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The Effect of On-Line Videos on Learner Outcomes in a Mechanics of Materials Course

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AC 2011-1910: THE EFFECT OF ON-LINE VIDEOS ON LEARNER OUTCOMES IN A MECHANICS OF MATERIALS COURSE

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The Effect of On-Line Videos on Learner Outcomes in a Mechanics of Materials Course

Introduction

The Mechanics of Materials course is one of the core engineering courses included in the curriculum of mechanical, civil, mining, petroleum, marine, aeronautical, and several other engineering disciplines. As a core course, the Mechanics of Materials course typically has large enrollment. Initiatives aimed at improving the effectiveness of the engineering core courses can have a major impact on engineering education by virtue of the large number of students affected.

Computers afford opportunities for creative instructional activities that are not possible in the traditional lecture-and-textbook class format. The study described in this paper examines the effectiveness of asynchronous online video that has been used in various ways in a Mechanics of Materials course over the past four years. The content delivered via the Internet included concept videos, problem-solving videos, and videos of demonstrations and laboratory activities.

In this study, four differing approaches to present the Mechanics of Materials course to approximately 1000 students in 17 course sections over a four-year period were compared. The first approach involved traditional, face-to-face lectures. The second approach completely replaced the face-to-face lectures with videos recorded by the instructor outside of the classroom, but covering the same topics as the classroom lectures, and then posted to a class web site. The instructor was available in his office during class time to answer questions. The third approach combined face-to-face lectures with videos. The fourth approach was an *inverted* format where students watched videos at home and worked on homework during class.

Using common final exam scores as a quantitative measure of effectiveness, results showed that overall student performance was maintained as class sizes and instructor workloads increased. Additionally, there was some indication that the inverted approach was better suited for higher-ability students.

Method

Instructors teaching statics, dynamics, and mechanics of materials at Missouri University of Science and Technology experienced a dramatic increase in teaching load starting in approximately 2006 due to increasing enrollments and decreasing funding. Figure 1 shows the number of lecture students taught and laboratory students supervised by a single instructor over the past ten years. Included are enrollments for all of the instructor's courses and not just the introductory mechanics courses. To cope with this increasing workload, mechanics of materials instructors began experimenting with that course's exam format in 2006 and its presentation format in 2008.

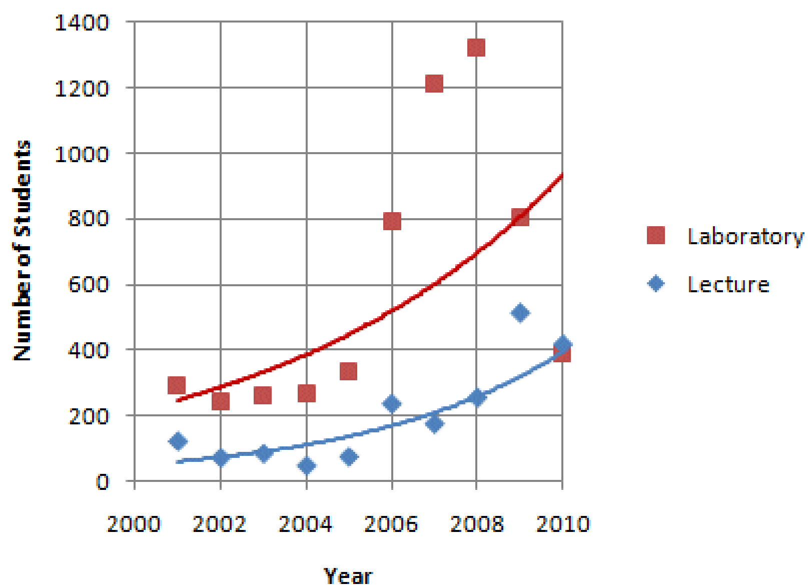

Figure 1. Changes in teaching load for an individual instructor.

Exam Format

Prior to 2006, the course had a common schedule and common homework assignments. Instructors collected weekly written homework assignments and gave four in-class exams and a common final exam. The in-class exams typically consisted of four problems and the final exams had eight problems. Each problem typically required one-half to one full page of written work. All of the exams were graded by hand, and partial credit was given for partially-correct solutions. During the summer and fall of 2006 and the spring of 2007, the instructors experimented with a combination of short and long exam problems. Many of the in-class exams and all of the final exams used in the fall of 2007 and afterwards consisted of 12 to 33 short problems. For the instructor, the use of shorter problems was necessitated by the need to grade exams in a timely manner.

The short exam problems were modeled after those of the Fundamentals of Engineering exam administered by the National Council of Examiners for Engineering and Surveying. The primary goal in creating these problems was to limit how far an error could propagate through a student's work and therefore make it easier to assign partial credit. The instructors began by examining the homework problems typically used in the course and dissecting them into categories that typically require only one or two formulas to solve. Teaching assistants then helped create approximately 100 exam problems per chapter.

Beginning in the summer of 2008, the final exam format was converted to multiple choice with limited or no partial credit and has remained that way. To deter cheating on the multiple choice exams, four to ten versions of each exam were given. Originally, the versions had different problems, but, as the problem-creation process matured, each version had the same problems but different numbers.

A spreadsheet was created to streamline the grading process. This provided statistics for each problem (and category) and allowed scores to be more easily loaded into the course-management software.

Evolution of Course Presentation Format

Prior to 2008, all of the instructors used traditional chalk-and-talk style lectures along with a variety of educational aids, like worksheets, partial or full problem solutions in the campus library or on a class web site, MecMovies animated example problems and exercises, and real-life failed components that could be passed around the classroom. A separate laboratory course accompanied the lecture course. Average section sizes increased from 35 students in 2003 to 50 students in 2006 to 100 students in 2010.

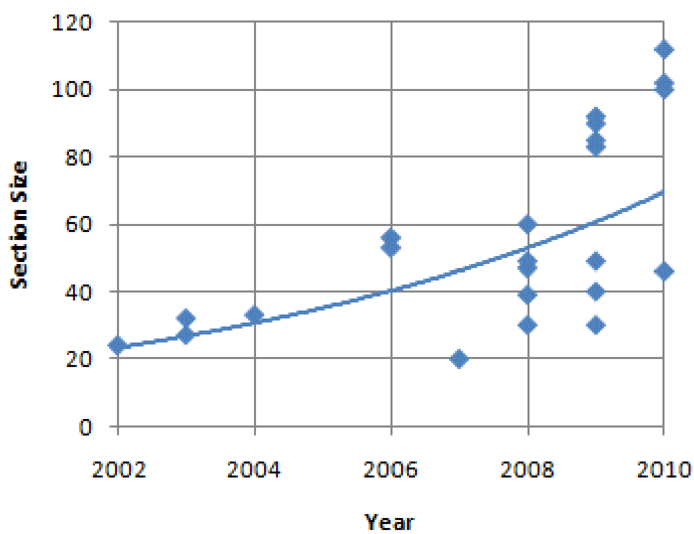

Figure 2. Changes in section size for an individual instructor.

During the summer of 2008, one section was offered, and it was taught with seventy-five percent of the face-to-face lectures replaced by asynchronous online videos. The course was offered five days a week. Each Monday the instructor and students met in the classroom to discuss the week's topics – generally two chapters from the textbook. On Tuesday through Thursday, the instructor was available in his office during class time to answer questions but did not hold class. Instead, the instructor recorded short video clips (described in the next section) and posted them to a class web site. Each Friday, the class met for an exam. Homework was assigned but not collected. The same final exam that had been given in the spring was given, and the results were nearly identical. The instructor invested a considerable amount of time creating videos and was involved in more one-on-one tutoring than usual.

In the fall of 2008, five sections of about equal size were offered. One instructor taught three sections using the same videos-replace-lecture approach as the previous summer, and another instructor taught the remaining sections with traditional lectures. Eight common in-class exams and a common final exam were given, and section averages were nearly identical.

In the spring of 2009, all four sections were taught by one instructor using traditional lectures while the online videos remained available. Classroom attendance was required of those that scored below 70% on the exams. Of those required to attend, 86% actually did. Of those not required to attend, 69% did.

In the summer of 2009, one section was offered, and students were again given the option to attend face-to-face lectures and/or watch videos. Attendance was not required.

In the fall of 2009, one section was taught by an instructor using traditional lectures. Another instructor taught two sections using the traditional-lecture-and-video approach, and attendance in this section was typically less than 50%.

In the spring of 2010, one instructor taught one section using traditional lectures. Another instructor taught a section on another campus using traditional lectures. A third instructor taught two sections using the traditional-lecture-and-video approach, and attendance in this section was typically 25 to 50%. The instructor also worked with a team of educational designers to improve the approach. The class web site was made more compatible with mobile devices, learning objectives for each chapter were tied directly to exam topics, more-thorough policies and a frequently-asked-questions page were developed, and new kinds of videos were recorded.

In the summer of 2010, one section was offered, and it was taught using an inverted approach. Twenty five percent of the lectures were taught face-to-face. On the other, non-exam days, the instructor actively tutored students as they worked homework problems. The instructor often spent the entire class time hurriedly answering questions from individuals or teams of students. Attendance at these optional sessions was 25-50%. The instructor used the same exams as in the spring, with similar results. Google Analytics was tied into the class web site to track usage.

In the fall of 2010, one instructor taught two sections using traditional lectures. Another instructor taught one section using the inverted approach, and attendance in this section was typically less than 25%.

All of the sections taught from Fall 2007 to Fall 2010 used the same short style of final-exam questions, the same textbook, MecMovies, and the same accompanying laboratory course. The same instructor taught all of the sections involving videos. To look at the effect of videos, only that instructor's sections taught in the time period of Fall 2007 to Fall 2010 were used in the following analysis. Table 1 summarizes the number of students, presentation format, and exam format for that instructor.

<table>
<tr><th>Semester</th><th>Students Per Section</th><th>Presentation Format</th><th>Number of Exams</th><th>Final Exam Problem Format</th></tr>
<tr><td>2002 Fall</td><td>24</td><td rowspan="8">traditional lectures</td><td rowspan="8">5</td><td rowspan="5">long</td></tr>
<tr><td>2003 Spring</td><td>27</td></tr>
<tr><td>2003 Fall</td><td>32</td></tr>
<tr><td>2004 Spring</td><td>33</td></tr>
<tr><td>2006 Spring</td><td>56</td></tr>
<tr><td>2006 Summer</td><td>53</td><td>long and short</td></tr>
<tr><td>2007 Fall</td><td>20</td><td rowspan="10">short</td></tr>
<tr><td>2008 Spring</td><td>30</td></tr>
<tr><td>2008 Summer</td><td>39</td><td rowspan="2">videos replace lectures</td><td rowspan="2">8</td></tr>
<tr><td>2008 Fall</td><td>60, 47, 49</td></tr>
<tr><td>2009 Spring</td><td>30, 49, 90, 80</td><td rowspan="4">traditional lectures and videos</td><td rowspan="6">9</td></tr>
<tr><td>2009 Summer</td><td>40</td></tr>
<tr><td>2009 Fall</td><td>92, 85</td></tr>
<tr><td>2010 Spring</td><td>102, 100</td></tr>
<tr><td>2010 Summer</td><td>46</td><td rowspan="2">inverted</td></tr>
<tr><td>2010 Fall</td><td>104</td></tr>
</table>

Table 1. Summary of format changes for the instructor that used videos.

Video Content and Equipment

Asynchronous course videos allow students more flexibility. Students can make up for classes missed due to illness, sports events, design competitions, and interviews oftentimes without the instructor even being aware of the absence. Students with certain disabilities, such as visual, auditory, or attention span, can benefit from the availability of videos. Students can refer back to videos while taking follow-on courses and while preparing for the Fundamentals of Engineering exam. Videos can also provide consistency across sections, instructors, and semesters.

The videos used in this course were designed from the viewpoint that new content should replace existing content, instead of adding to it. The instructor approached the videos-replace-class and inverted formats with the idea that *information* should be delivered with videos and *interaction* should be delivered during class time to only those that desire it.

Different types of videos were used. First, videos borrowed from YouTube provided news reports on failed structures and lab experiments performed at other universities. *Concept* and *problem* videos were recorded using a tablet PC, screen-capture software, and a headset. As one would expect, the concept videos covered the basics of a given topic, and problem videos showed examples being worked step-by-step. Some problem videos covered strategies for working certain types of problems and how to recognize one problem type from another. *Demonstration* and *experiment* videos were recorded using video cameras and either a headset or a hand-held microphone. The demonstration videos showed real-life, failed components either being manipulated in the instructor's hands or spun on a turntable. The experiment videos were recorded in a laboratory and showed specimens being loaded and their related data. Table 2 summarizes the number of videos created, their length, and how students used them (according to Google Analytics).

Type of Video	Number of Videos, Total Length, and Server Space	Average Video Length	Average Length Watched by Students	Number of Views by About 100 Students During Fall 2010
borrowed (YouTube)	10 videos, 30 minutes	2.7 minutes	–	–
concept	49 videos, 4 hours, 140 MB	5.4 minutes	5.0 minutes	2060
problem-solution	140 videos, 20 hours, 510 MB	8.4 minutes	5.7 minutes	5798
problem-strategy	6 videos, 2 hours, 55 MB	16.7 minutes	5.5 minutes	136
demonstration	28 videos, 1 hour, 215 MB	1.9 minutes	1.4 minutes	676
experiment	5 videos, 10 minutes, 30 MB	2 minutes	1.7 minutes	83

Table 2. Type and number of videos used in the course.

Figures 3 through 7 show examples of the various video types. Figure 3 is from a concept video on axial stress. Figure 4 is from a demonstration video on torsion-related failures. Figure 5 is from a problem-strategy video pertaining to shear strains. Figure 6 is from a problem-solution video on combined loadings. Figure 7 is from an experiment video showing a steel tension test and annotated graph overlay.

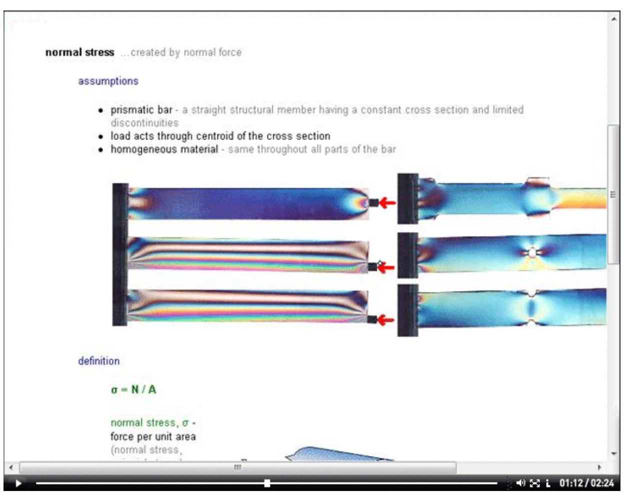

Figure 3. Concept video.

Figure 4. Demonstration video.

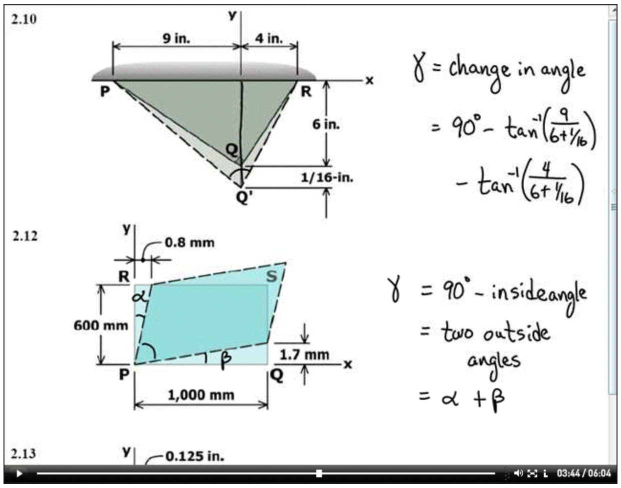

Figure 5. Problem-strategy video.

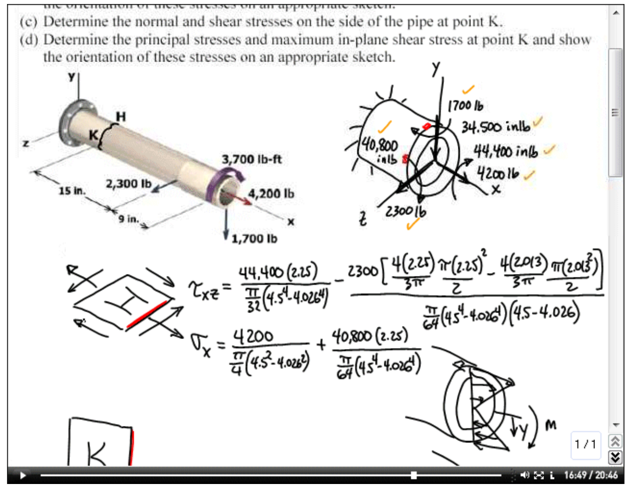

Figure 6. Problem-solution video.

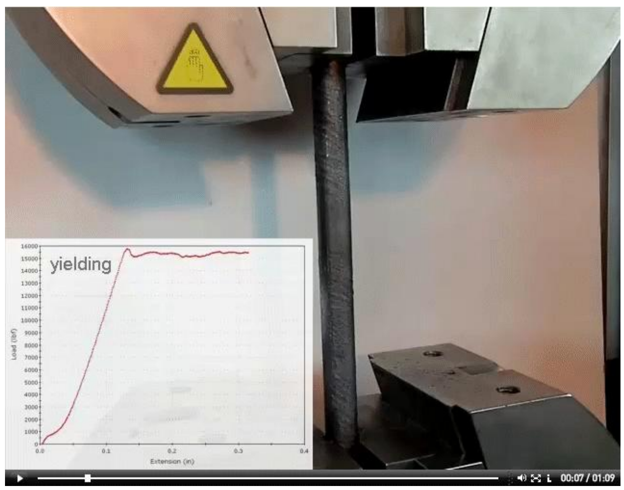

Figure 7. Experiment video.

Thirty eight additional videos were created for the laboratory course that accompanies mechanics of materials. These included concept, demonstration, and experiment videos. Their primary purpose was to train the graduate and undergraduate teaching assistants assigned to the course, but they were also made available to the students taking that course.

None of the videos, for the lecture or laboratory courses, were recorded in a classroom, and none of the videos showed the instructor, except for his hands in some of the demonstration videos. Instead, the videos were created at home, at the office, or in the laboratory. They were designed to be short and modular in order to maintain student interest, help students more easily locate relevant information, and help the instructor update individual topics or problems over time. Noting the approximate five-minute ceiling in student usage from Table 2, the authors plan to use this as a guide for future recordings.

The development time required to create and produce a finished concept or problem-strategy video was typically 2-3 times the duration of the finished video. Demonstration videos required more development time, typically 3-4 times the duration of the finished video. Problem-solution videos required development time of 4-5 times the duration of the finished video. Included in the development time required for these types of videos was time to work the problem beforehand so that the instructor did not have to spend unnecessary time on intermediate calculations during the video presentation. Videos of experiments were the most time-consuming to produce, taking up to 100 times the duration of the finished video, depending on the complexity of the setup and data analysis.

Figure 8 shows how multiple cameras, lights, and an external microphone were arranged for experiment videos. Screen-capture software was commonly used to simultaneously record graphs being plotted in the testing software as the experiment was in progress. Video-editing software was later used to merge the test and graph videos. The articulated boom of a Benbo Trekker tripod proved useful in moving the cameras in close to the specimens. Casio EX-F1cameras allowed for (limited) high-speed photography on a consumer-level budget.

Figure 8. Typical setup for experiment videos.

Figure 9 shows how some of the demonstration videos were recorded, using a photography table (MyStudio 32), cake turntable (KopyKake Karousel Turntable T1000), and additional light fixtures. Early attempts at demonstration videos simply utilized an ordinary table and desk lamp.

Figure 9. Typical setup for demonstration videos.

Figure 10 shows how the cameras, photography table, and several computers, running either screen-capture or camera-control software, were eventually arranged in an instructor's office. This office is adjacent to the laboratory, and the system was designed so that the cameras can be quickly repositioned for an experiment, while still being controlled and monitored from the office, and then moved back into the office. A combination of electrical, audio-visual, and musical-instrument hardware was used to suspend the cameras, lights, and monitors. Certain components from Pearl Drums and Gibraltar Hardware were found to be cheaper than similar audio-visual hardware, still allowed for rigid but flexible positioning, and fit commonly available EMT tubing and strut channel. The authors plan to use this setup for future recordings, and other studios on the campus are being modeled after it.

Figure 10. An instructor's recording and editing studio.

Course Web Site

A course web site was established in 2002, and as of the fall of 2010 it contained 1800 HTML files, 3000 graphics, and the videos previously described. Strategy guides for 300 homework problems and full solutions to 465 homework problems were prepared by the instructor and made available to the students. Figure 11 shows a typical chapter page. It contains the learning objectives for that chapter, links to the instructor's notes and concept videos, links to the demonstration videos, and links to the homework videos, strategies, and solutions. There are also a couple examples per chapter on how to solve homework problems using ANSYS, in case a student is curious about computer simulations.

Chapter 8 - Bending

Objectives

Course objective: To learn to calculate the stresses for beams under various loading configurations.

Learning objectives:

- Calculate a beam's *curvature* due to a bending moment.
- Calculate the centroid location in i-beam, tee, and channel shaped cross sections.
- Calculate the area moment of inertia in i-beam, tee, and channel shaped cross sections.
- Acquire relevant data for *named* beams from the geometry tables in the appendices.
- Calculate section modulus based on a beam's centroid and area moment of inertia.
- Identify a beam's controlling section modulus.
- Draw a beam's shear-force and bending-moment diagrams.
- Calculate normal stress due to bending for symmetric (rectangle, tube, i-beam) and non-symmetric (tee, channel) beams.
- Determine optimum beam geometry based on allowable stresses.
- Transform beams made of two materials into a single-material equivalent.
- Combine normal stresses due to axial loading and bending on eccentrically-loaded beams (rectangular, pipe, tee).

Concepts (37 minutes)

1. semester overview video notes
2. beam flexure video notes
3. composite beams video notes
4. combined loading video notes
5. homework strategies
   - problems 32 through 60 video

Demos (8 minutes)

1. foam beam video
2. c-clamp video
3. hacksaw video

Problems (144 minutes)

	2e	1e				
bending	08.001*	08.001	video	--	solution	--
	08.002*	08.002	--	--	--	--
	08.003*	08.003	--	--	--	--
	08.004*	08.004	--	--	solution	--
	08.005*	08.005	--	--	--	--
	08.006*	08.006	--	strategy	solution	--
	08.007*	08.007	--	--	--	--
	08.008*	08.008	--	strategy	solution	--
	08.009	08.009	video	--	solution	--
	08.010	08.010	--	strategy	solution	--
	08.011	08.011	--	--	--	--
	08.012	08.012	video	--	solution	--
	08.013	08.013	--	--	--	--
	08.014	08.014	--	--	--	--
	08.015	08.015	--	--	--	--
	08.016	08.016	--	--	solution	--
	08.017	08.017	video	--	solution	ansys
	08.018	08.018	--	strategy	solution	--
beams	08.019	08.019	video	--	solution	--
	08.020	08.020	--	strategy	solution	--
	08.021	08.021	--	--	--	--
	08.022	08.022	--	strategy	solution	--
	08.023	08.023	--	--	--	--
	08.024*	08.024	video	--	solution	ansys
	08.025	08.025	--	--	--	--
	08.026*	08.026	--	--	--	--
	08.027	08.027	--	--	--	--
	08.028	08.028	--	--	--	--
	08.029	08.029	--	strategy	solution	--
	08.030	08.030	video	--	solution	--
beam design	08.031	08.031	--	--	--	--
	08.032	08.032	--	strategy	solution	--
	08.033	08.033	--	--	--	--
	08.034	08.034	--	strategy	solution	--
	08.035	08.035	--	--	--	--
	08.036	08.036	--	--	--	--
	08.037	08.037	--	--	--	--
	08.038	08.038	--	strategy	solution	--
	08.039	08.039	video	--	solution	--

Figure 11. Typical chapter page on course web site.

Figure 12 shows a problem strategy for beam deflection, and Figure 13 shows a problem solution for combined loadings. These are images that are available on the web site and not videos. Note that the video in Figure 10 is for the same problem as the solution shown in Figure 13. Even though both are handwritten on a tablet PC, the solution images tend to be more polished than the solution videos, because it is much easier and quicker to refine a fixed image.

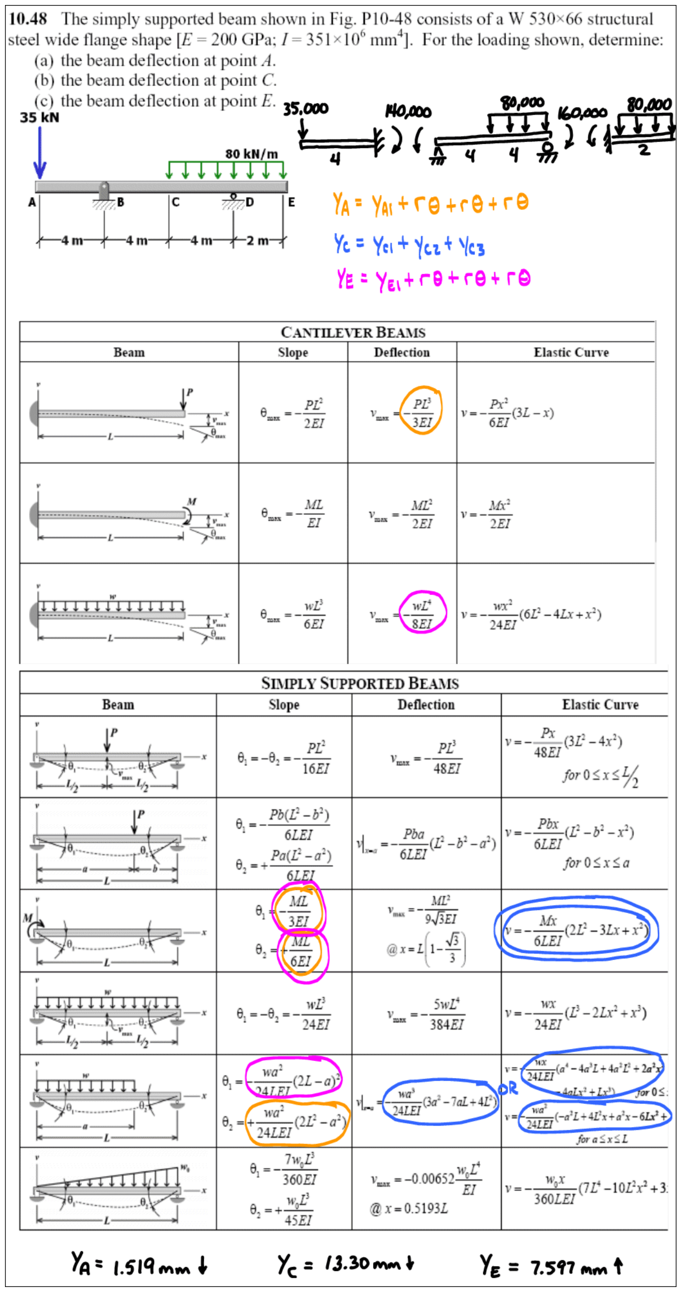

Figure 12. Problem-strategy image.

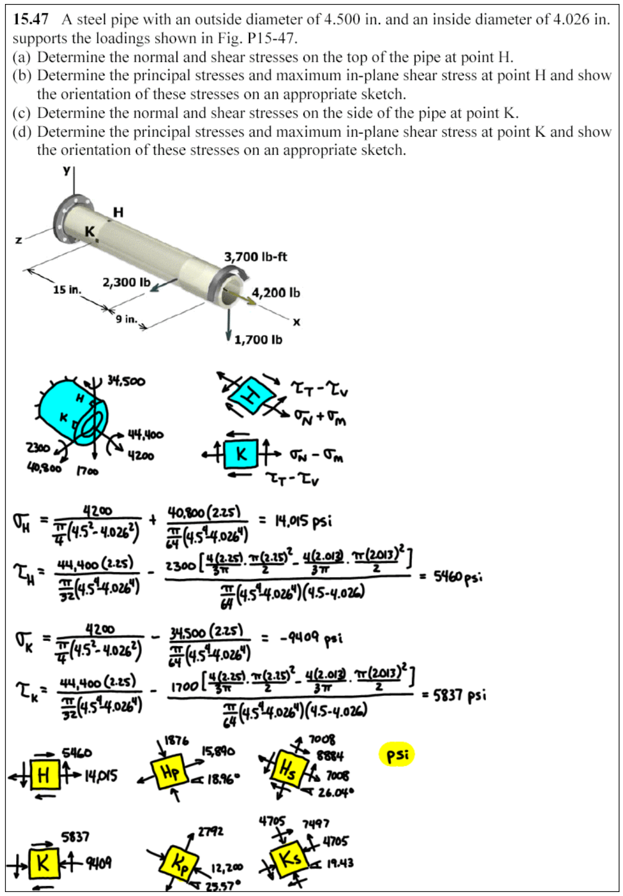

Figure 13. Problem-solution image.

According to usage data compiled by Google Analytics, students access the problem images far more than the problem videos. Table 3 summarizes how often and for how long each part of the web site was utilized by about 100 students during the fall of 2010. The items are ranked according to the total amount of time the items were accessed during that semester.

Site Component	Total Time on Page (hours)	Number of Times Accessed	Average Time on Page Per Access (minutes)
problem-solution image	2295	41517	3.3
lecture notes	706	54112	0.8
problem-solution video	554	5798	5.7
problem-strategy image	516	10105	3.1
course schedule	421	19967	1.3
concept video	171	2060	5.0
old exams	140	3169	2.7
grades page	128	2552	3.0
course policies	20	368	3.2
demonstration video	15	676	1.4
frequently-asked-questions page	15	375	2.4
problem-strategy video	12	136	5.5

Table 3. Web site usage by 100 students for one semester.

Google Analytics also provided the following information for the fall semester of 2010. There were 15,000 visits to the web site and 141,000 page views. The average number of page views per visit was 9, and the average time per visit was 17 minutes. For browsers, 38% of the visitors used Firefox, 22% used Internet Explorer, 19% used Chrome, and 19% used Safari. For operating systems, 73% of the visitors used Windows and 23% used Macintosh. For connections speeds, 47% of the visitors used T1, 29% used cable, 15% used DSL, and 1% used dialup. Mobile devices accounted for 4% of the visits, with 47% of those being iPhone, 30% being Andriod, 9% being Blackberry, 7% being iPod, and 5% being iPad. During the same period of time, the laboratory web site received 5,600 visits and had 24,400 page views.

Results

Effect of Video

In order to assess the impact of video on student performance, the class sections were combined to form four video conditions as follows: Traditional (Fall 2007 & Spring 2008); Video Replaces Class (Summer 2008 and Fall 2008); Traditional with video available (Spring 2009, Summer 2009, Fall 2009, and Spring 2010); and inverted (Summer 2010 and Fall 2010). Final exam scores served as the dependent variable.

These conditions were then compared in a one-way, between-subjects analyses of variance (ANOVA) with final exam score serving as the dependent variable. The ANOVA was not statistically significant. The means are displayed in Table 4. Similar results have been found for video usage[1,2] and hybrid/inverted formats[3,4].

Performance Measure	Video Condition			
	Traditional (n = 50)	Video Replace Class (n = 195)	Traditional: video available (n = 668)	Inverted (n = 150)
Final Exam	71.74	73.92	75.85	73.14

Table 4. Mean final exam scores as a function of video condition.

Effect of Ability

In order to assess the moderational role of ability, a subset of the data was selected to compare the traditional with inverted video sections, including the Fall 2007 and Spring 2008 semesters (representing the **traditional** instructional presentation) and the summer and fall of 2010 (representing the **inverted** instructional presentation). Each student was also classified as having a high or low grade point average (GPA), based on a median split of grade point average.

Using these data, a two-way between-subjects analyses of variance (ANOVA) were computed with video condition (traditional vs. inverted) and grade point average (high vs. low) as the independent variables and final exam score as the dependent variable.

A main effect was found for GPA, $F(1,181) = 23.98$, $p < 0.001$, with those in the high GPA group ($M = 79.14$) scoring significantly higher than those in the low GPA group ($M = 64.98$). No other effects were significant. The cell means are displayed in Table 5.

GPA group	Video Condition	
	Traditional (n = 50)	Inverted (n = 150)
High GPA	76.66	81.63
Low GPA	66.06	63.91

Table 5. Mean final exam score as a function of video condition and GPA.

Conclusions

The educational innovations described in this paper were driven by a need to maintain high academic performance in an era of rapidly escalating class sizes and instructor workloads. The data gathered in this study show that overall student performance was maintained as course presentation evolved from the traditional lecture format to an asynchronous format that relies heavily on Internet delivery of instructional materials. Closer examination of student performance, as indicated by the objective final exam score measure, suggests that higher-ability students may perform somewhat better using the asynchronous format while lower-ability students may perform slightly worse. However, these differences between higher- and lower-ability groups were not statistically significant.

Overall, the data presented here offer encouragement for continued development of asynchronous delivery of problem-solving courses such as mechanics of materials. While proper development of such courses requires a substantial initial investment in the preparation of educational media, this study has shown that student performance can be maintained while enabling fewer instructors to teach greater numbers of students.

Support

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